Late Cretaceous Flora in an Ancient Fluvial Environment: The Lower Cantwell Formation at Sable Mountain, Denali National Park, Alaska

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Abstract

The lower Cantwell Formation is a late Cretaceous fluvial deposit that contains dinosaur footprints and plant fossils. Facies analysis of numerous conglomerate, sandstone, siltstone, and shale successions in the Sable Mountain area in Denali National Park and Preserve reveals a variety of depositional settings, including channels, overbank, crevasse splays, lakes and ponds, located in close proximity on an ancient floodplain or alluvial fan. Plant megafossils preserved in the finer-grained facies indicate that the Cantwell flora was a polar broad-leaved deciduous mixed forest with diverse angiosperms and several deciduous conifers. Combined sedimentological and paleobotanical studies allow identification of distinct local plant communities associated with each of the depositional settings. Dicotyledonous angiosperm leaf morphology was used to compute a mean annual temperature of 51.1°F (10.6 °C), a warmest monthly mean of 69.1°F (20.6 °C), and a coldest monthly mean of 34.7°F (1.5 °C). Climate in this high-latitude region was temperate, with mild winters and considerably warmer summers than those that prevailed on Alaska's North Slope during the Late Cretaceous.

Introduction

The Cantwell Formation crops out in the foothills and northern mountains of the Alaska Range in southcentral Alaska. In Denali National Park and Preserve (Denali Park) the formation can be readily recognized from the park road by its precipitous cliffs and dramatic bluish black, yellow and reddish colors. Exposures in the Sable Mountain area in Denali Park consist of numerous successions of conglomerates, tabular and lenticular sandstones, organic-rich siltstones and shales. Plant fossils and recently discovered dinosaur footprints, bird footprints, and diverse invertebrate traces indicate a flourishing terrestrial ecosystem in a high-latitude environment (*Fiorillo et al. 2007*), as the Cantwell basin was probably located at a paleolatitude > 65 °N at the time of deposition (*Spicer et al. 1987*). Analyzed in lithological context, the plant fossils of the lower Cantwell Formation provide new information about the landscape, vegetation, climate and depositional processes for this Late Cretaceous basin.

Geologic Background

Beginning about 90 million years ago, Alaska grew in size as small segments of northward-displaced lithospheric crust (terranes) collided with the former southern Alaska plate margin (*Plafker et al. 1994*). The terrestrial Cantwell Formation was deposited during the final accretionary phase of the composite Wrangellia terrane to the North American continent (*Ridgway et al. 1997*). Now located within the Denali Fault system, the Cantwell Formation forms a 22 mile (35 km) wide, about 78 mi (125 km) long, east-west trending belt along the northernmost edge of the Alaska Range. The formation comprises a 2.5 mi (4 km) thick fluvial sedimentary succession of late Campanian to Maastrichtian age (75 to 70 million years in age) (*Ridgway et al. 1997*) and an upper volcanic unit of Paleocene and Eocene age (60 to 55.5 million years in age) (*Cole et al. 1999*). Both the upper and lower Cantwell Formation were folded and faulted during subsequent tectonic deformation and then uplifted during the rise of the Alaska Range. At Sable Mountain, the older sedimentary rocks are well exposed (*Figure 1*).

Fluvial Lithofacies and Facies Associations

A floodplain constitutes a low-gradient land surface that is drained by a major river and its tributaries. It is not a static environment. Here streams erode, transport and redistribute sediments as they change their course. In between streams and rivers, marshes, lakes and ponds develop in low-lying areas where drainage conditions are poor. Fine sediment accumulates slowly during ephemeral floods as the basin subsides. Levees form where coarser sediment builds up during overbank floods or where channels incise into older sediments. As a result, different depositional environments such as channels, levees,

Photograph by C.S. Tomsich

Figure 1. The sedimentary lower Cantwell Formation exposed at Sable Mountain in Denali National Park.

crevasse splays, lakes, ponds and floodplain develop next to each other and succeed one another; the changing dynamics produce a variety of lithologies (facies) and facies assemblages in an alluvial setting. Habitat preference, frequency of recurring floods and soil quality determine the types of vegetation that will grow in these different fluvial environments. Sedimentary and fossil records thus harbor complementary paleoenvironmental information.

Sedimentary Facies of the lower Cantwell Formation

Facies 1: Massive conglomerate

This facies contains clasts up to 6 inches (15 cm) in diameter with a predominantly matrix-supported texture. Deposits are often trough-shaped, winnow out laterally and are rarely more than 13 ft (4 m) thick. Moderately sorted clasts are subangular to wellrounded and occur in coarse to very coarse, subangular to subrounded sand. Typically conglomerates contain lenses of sand or thin layers of mud, dividing the deposits into multiple stories. Bedding is cross-stratified or massive. Tree trunk impressions are common. Facies 1 is interpreted as gravelly channel fill.

Facies 2: Pebbly sandstone

Facies 2 consists of tabular or lens-shaped coarse- to medium-grained, pebbly sandstones less than 20 ft (6 m) thick that grade laterally into finer-grained, organic-rich facies. Angular to well-rounded pebbles ranging in size from 0.1 to 2 in (0.3 to 5 cm) commonly rest on low-angle foresets. Deposits are massive or trough cross-stratified and grade upward into medium sandstone. Facies 2 is interpreted as levee, small channel or crevasse splay channel fill.

Facies 3: Coarse- to medium-sandstone

Tabular and lenticular coarse- to medium-grained sandstone bodies embedded in finer-grained deposits are typically less than 3.3 ft (1 m) thick. Deposits are massive, planar, or trough cross-bedded and may have granules on foresets. Sand grains are predominantly subangular and moderately sorted. Facies 3 is interpreted as levee, small shallow channel fill and overbank sheetflood deposits.

Figure 2. (A) Twig of the taxodiaceous conifer *Metasequoia*. (B) A 6.6 ft (2 m) high in situ *Metasequoia* tree trunk and shallow root impression in channel sands. The tree was growing in the floodplain before being incorporated into the deposits of a migrating channel.

Facies 4: Fine sandstone

Facies 4 is a tabular or lenticular sandstone embedded in finer-grained deposits consisting of subangular to subrounded grains. Bedding is massive, rippled or trough cross-stratified with rare mud on foresets. This sandstone is typically burrowed and moderately rooted. It frequently contains twigs and cones of *Metasequoia, Equisetum* rhizomes and stems, leaf impressions and wood. Facies 4 is interpreted as small channel fill, crevasse splay, and sheetflood deposits.

Facies 5: Interbedded fine to very fine sandstone and siltstone

This facies consists of laterally extensive decimeter- to centimeter-scale tabular beds of interbedded fine-to very fine-grained sandstone and siltstone that often grade into siltstone. Sandstone is massive or rippled. Deposits contain invertebrate trace fossils and abundant plant macrofossils. Roots and concretions indicate weak soil development.

Figure 3. Pinnately-veined leaf impressions. Such fossils occur in crevasse splay and overbank deposits.

Facies 5 is interpreted as crevasse splay, sheetflood, levee and overbank deposits.

Facies 6: Interbedded fine to very fine sandstone and mudstone

Facies 6 is a centimeter to millimeter-thick fine- to very fine-grained, tabular sandstone interbedded or interlaminated with mudstone. It may be rippled, trough cross-bedded or laminated and contain small traces made by beetles, gastropods, ostracodes and annelids. Plant macrofossils are abundant; and roots and concretions are evidence for soil development. This facies is interpreted as distal crevasse splay, sheetflood, levee and overbank deposits.

Facies 7: Siltstone

Facies 7 is a dark grey to black siltstone, centimeters to tens of meters thick. It is organic-rich and may be interlaminated with mudstone. This facies contains conifer needles, *Equisetum* rhizomes, carbonaceous roots and other plant fragments. Iron concretions or nodules are very common. Beds typically show irregular relief at the top that was likely caused by dinoturbation. This facies is interpreted as distal crevasse splay, floodplain and lake margin deposits.

Facies 8: Mudstones and shales

This very fine-grained facies consists of dark grey to black organic-rich mudstone and shale that is usually 0.4 in to 3.3 ft (1 cm to 1 m) thick, rich in clay, and locally calcareous. Mudcracks may be seen at the surface or beds may be irregular due to erosion and bioturbation. Facies 8 typically occurs in coarser-grained deposits in the form of rip-up clasts. Fossils consist of *Equisetum* segments, small, frequently coalified, plant fragments, carbonaceous rootlets, and bivalve and gastropod shells. This facies is interpreted as floodplain, shallow lake or pond deposits.

Facies 9: Unorganized deposits

Facies 9 contains clasts of all sizes, pieces of wood, and mud rip-up clasts in a sandstone or organic-rich mudstone matrix. Deposits are often poorly consolidated, infrequent and occasionally contain in situ tree stump impressions. We interpret Facies 9 as debris flows.

Alluvial deposition

The facies and facies associations in the lower Cantwell Formation indicate that the rocks at Sable Mountain represent alluvial sheetfloods, braided channels, crevasse channels and splays, overbank and levee deposits, small shallow lakes or ponds and floodplain sediments. Lithologies reflect sedimentary processes typical of low-lying fluvial environments. The sedimentary environment has been characterized as an alluvial fan system drained transversally by an axial sandy braided river (*Ridgway et al. 1997*). The many tabular sandstones and floodplain fines at Sable Mountain indicate that deposition occurred close to the center of a fluvial valley either at the distal end of an alluvial fan lobe where ephemeral floods would have been common (*Leeder 1999*) or in the floodplain of a trunk river and its tributaries. Poorly organized colluvial deposits (Facies 9) in the Sable Mountain area and elsewhere in the basin (*Ridgway at el. 1997*) suggest that the tabular sheetflood sandstones may be periodic, distal alluvial fan stream flow deposits. However, trough-shaped conglomerates and coarse sandstones in extensive floodplain fines signify that alluvial fan sediments interfinger with the floodplain deposits of the main river system that drained the ancient valley.

The different lithologies and geometries of the sediment created a variety of local habitats with different drainage conditions. For example, the numerous successions of shallow, fine-grained sandstones and siltstones suggest that overbank floods were frequent but that deposition was quickly abandoned as waters receded. Abundant roots in the interbedded sandstones suggest that these facies allowed for a rapid re-vegetation of the disturbed areas. The lithology of the deposits becomes finer-grained with increasing distance from active streams. Marshy lowlands and standing water bodies developed in poorly drained areas. Minor paleosol development in floodplain fines signals predominantly wet conditions. As fluctuating water tables generally affect soil formation and consequently plant species distribution, a riparian vegetation would have been required to readjust with each change to the depositional setting (*Dwire et al. 2006*).

The Fossil Flora of the Lower Cantwell Formation

The lower Cantwell Formation yields abundant plant impressions including the stems and rhizomes of horsetails (*Equisetum*); fronds of schizaceous and gleichenaceous ferns and of *Cladophlebis*, an extinct fern; leaves, cones and seeds of the deciduous conifers *Metasequoia* (*Figure 2*) and *Glyptostrobus*; fragments of ginkgophytes, cycadophytes, diverse dicotyledonous angiosperm leaves (*Figures 3-4*), and the monocot *Sparganium* (Thypha) and other unidentified blade-like leaves. Also present are log impressions (*Figure 2B*) and lithified wood. Sparse and poorly preserved fossil pollen grains and spores extracted from organic-rich mudstones yielded the angiosperm pollen taxa *Alnipollenites* and *Aquillapollenites*, the coniferous pollen taxa *Taxodiaceaepollenites*, few cycad or ginkgo pollen grains, and abundant horsetail and fern spores.

Angiosperm leaf fossils have simple forms with palmately, pinnately or palmately-pinnately venation, but fragments of large palmately-lobed leaves also occur. Leaf sizes range from 0.6 in (1.5cm) to an estimated 20 in (50 cm), based on vein spacing. The majority of the taxa belong to the families Platanaceae, Nymphaeaceae, Menispermaceae and Hamamelidaceae. Of the platanoid types forms such as *Pseudoprotophyllum* are rare while leaves of betulaceous morphology (cf. *Corylites* and *Alnites*) are especially abundant. Other taxa such as *Viburniphyll* and the trochodendroid, zizyphoid and the vine-like menispermoid groups often occur in association with the platanoids and remains of taxodiaceous conifers. In all, 21 angiospermous morphotypes were identified from the study area on the basis of leaf organization.

The depositional habitat environments

Plant fossils recovered from fluvatile facies approximate the composition of an ancient local flora (*Spicer and Parrish 1990*). At Sable Mountain the sandier deposits apparently favored leaf preservation due to better drainage and rapid accumulation. Fossil assemblages are more diverse in levee, crevasse splay, and overbank deposits than in floodplain and lake facies, and plant community associations are interpreted to correspond to three sub-environments: stream margin, elevated floodplain and low-lying floodplain.

Angiosperm leaf taxa appear individually or as part of a mixed forest litter. Platanoid trees or shrubs grew predominantly along streams (*Facies 2 and 3*). A more complex assemblage containing *Metasequoia* leaves and cones and diverse hamamelid angiosperm leaves are found primarily in sandy overbank deposits and embankments (*Facies 3-6*). The finer-grained and more organic-rich floodplain facies (*Facies 5-7*) contain elements of the conifer *Glyptostrobus*, the angiospermous leaves *Alnites*, *Menispermites*,

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Figure 4. Palmately-veined trochodendroid leaf impression. These leaf fossils are common in crevasse splay, overbank and levee deposits, and to a lesser degree in floodplain and lake margin deposits.

and *Sparganium*, rare cycad leaves, *Equisetum* and a variety of ferns.

The different fossil assemblages signify that soil and drainage conditions varied within the floodplain according to facies distribution and frequency of river sand and fertile mud deposition. In better-drained and more built-up areas diverse angiosperm shrubs and small-diameter trees may have formed an open canopy forest together with *Metasequoia*. In contrast the dominant lowland vegetation in the floodplain and along the lake and pond margins consisted of a low-diversity flora, which included platanoids, nymphaelalean vine-like plants, a variety of ferns and hydrophilic gymnosperms. Cycads, *Equisetum* and herbaceous plants covered the marshes.

Geographic species distributions and paleoclimate

The Cantwell Flora contains elements that are present in other Arctic floras. Taxodiaceous conifers such as *Metasequoia* and *Glytostrobus* and species of the dicot leaf genera *Trochodendroides*, *Menispermites*, *Zizyphoides*, *Pseudoprotophyllum*, *Corylites*, the monocot *Sparganium* and the ferns *Gleichenia* and *Cladophlebis* were widespread in the Arctic during the late Cretaceous (*Hollick 1930, Spicer et al. 1987, Budantsev 1992, Herman and Spicer 1995*). Yet, even though as these genera are well represented in the Cantwell flora, it is still unclear how they relate at the species level given that very few species could be identified.

Fossil leaf character correlation with modern leaf physiognomies and climate variables has proven effective in computing ancient climate parameters (*Wolfe and Spicer 1999*). Using Climate Leaf Analysis Multivariate Program (CLAMP) (*Wolfe and Spicer 1999*), our first estimate for a mean annual temperature (MAT) is 51.1°F (10.6 °C), a warmest monthly mean (WMMT) is 69.1°F (20.6 °C) and a coldest monthly mean (CMMT) is 34.7°F (1.5 °C). In comparison, Spicer and Parrish (*1990*) calculated a MAT of 35.6 to 43°F (2 to 6 °C); and Parrish et al. (*1987*) estimated the WMMT at 50 to 53.6°F (10 to 12 °C) and the CMMT at 35.6 to 39.2°F (2 to 4 °C) for the Maastrichtian flora of the Prince Creek Formation which crops out on Alaska's North Slope. These results indicate that the Earth was much warmer at the time and that winters were mild. Variables computed for the Cantwell basin, however, show greater disparity between summer and winter temperatures. While the CMMT calculated for the two floras is very similar, average summer temperatures are significantly higher for the Cantwell data. This disparity could be a symptom of terrain and latitudinal differences. The North Slope at the time was a fluvio-deltaic setting facing the Arctic Ocean. It was located at approximately 85 °N, and angiosperm diversity was reportedly low (*Spicer and Parrish 1990*). The Cantwell basin, in contrast, was located further inland, 10 degrees or more to the south, opening toward an epicontinental sea to the east, the Cretaceous Western Interior Seaway (*Ridgway et al. 1997*). Results suggest a strong pole-ward summer temperature gradient possibly due to southward increases in insolation. Taxa and calculated temperatures indicate that the Cantwell flora like other late Cretaceous Arctic floras can be categorized as a polar coniferous and broad-leaved deciduous forest flora (see *Wolfe 1987*).

Conclusion

The late Cretaceous lower Cantwell Formation at Sable Mountain represents braided channel, small channel, crevasse splay, levee, overbank, floodplain, and lacustrine sediments and occasional debris flows typical for floodplain and/or distal alluvial fan deposition. Plant fossils analyzed in the context of lithofacies show that coniferous and angiospermous plants formed distinct floral community associations in a variety of depositional environments. Vertical facies successions and accompanying changes to the floral communities reflect altered hydraulic conditions during floodplain evolution. Taxodiaceous conifers and dicotyledonous angiosperms achieved significant diversity; taxa at the family and genus levels correspond to those described from other Arctic floras. Accordingly, the Cantwell flora is classified as a polar broad-leaved deciduous mixed forest flora. CLAMP analysis implies that climate in this high-latitude region was temperate, with mild winters and considerably warmer summers than those predicted for Alaska's North Slope during the Late Cretaceous. In this way, the paleofloristic data amend our understanding of vegetation distributions and past climate variability in ancient greater Beringia.

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